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Study on the treatment of soybean protein wastewater by a pilot-scale IC-A/O coupling reactor

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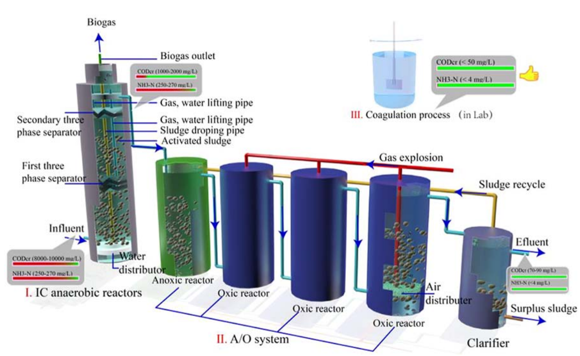
HIGHLIGHTS

- IC-A/O coupling reactor was started successfully in treating soybean wastewater.
- Proteobacteria and Bacteroidetes were the predominant phyla in IC-A/O system.
- Nitrospiraceae and Nitrosomonadaceae dominated the removal of nitrogen.
- COD_{Cr} and NH_3-N in IC-A/O effluent reached the required discharge standard.

GRAPHICAL ABSTRACT



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ABSTRACT

A pilot-scale internal circulation-anoxic/oxic (IC-A/O) coupling reactor was performed for soybean protein wastewater treatment. Results indicated that after the IC-A/O coupling system, the COD_{cr} (8000–10,000 $mg{\cdot}L^{-1}$) and NH_3-N (250–270 $mg{\cdot}L^{-1}$, decomposed from the organic nitrogen) in influent of soybean protein wastewater was greatly reduced to 70–90 $mg{\cdot}L^{-1}$ and $< 4\ mg{\cdot}L^{-1}$, respectively, which indicated a successful start-up of IC-A/O coupling system. The hydraulic retention time (HRT) of the IC reactor kept being 24 h with CODcr removal constant at 90% (pH of the reactor at 7.0–7.4). The inflow, NH_3-N and COD_{cr} volume loadings in the A/O system also affect the performance of the IC-A/O coupling system. The macrograph SEM indicated the spheroidicity-shaped anaerobic granular sludge (with diameter of 1–2 mm) in IC reactor, which mainly composed of large amounts of bacilli microorganisms playing a skeletal role in the sludge formation, with wrapped some cocci microorganisms; this also corresponded well with the analysis of bacterial community structure. SEM images of sludge morphology indicated that bacillus microorganisms played a predominant role on the microbial morphology of granular sludge not only in anoxic system, but also in oxic system. This result was proven by the overlap of OUT_1664 in Venn figure.

1. Introduction

The discharges of the soybean protein wastewater are extremely huge in China, which was partially due to the intensive interest of the soy proteins in a large diversity of soy food products [1–3]. The soy protein wastewater is always characterized as the high organic

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Table 1
Primary indicators of test water.

Parameter	COD_{cr} (mg/L)	BOD_5 (mg/L)	SS (mg/L)	NH_3-N (mg/L)	TN (mg/L)	TP (mg/L)	Temperature (K)	pH
Value	8000–20000	4000–9000	700–1000	80–120	300–800	150–280	308–318	3.5–4.5

wastewater containing bio-organic derivatives originating from aqueous solar cells electrolytes [4–6], which was composed mainly of soluble proteins and carbohydrates, with high chemical oxygen demand (COD) values and high nitrogen contents [3,7,8]. Besides, the water quality of the soybean protein processing wastewater always varies widely. To satisfy the specific regulatory discharge limits imposed by legislation, it is crucial to develop an appropriate biological innovative reactor for treating the soybean protein wastewater.

Recently, relevant studies on the soybean protein processing wastewater treatment mainly focused on the aerobic reactors and membrane technologies [9–12]. However, they have numerous demerits such as high sludge yield, membrane pollution and high-cost in operation, which greatly restricts the utilization in the field treatment system. It is regarded that anaerobic biological treatment is the most efficient technology to deal with these high organic loading wastewaters, partially because of their low energy consumption, less residual sludge generation and efficient energy recovery [8,13]. Currently, different kinds of anaerobic reactors have been developed in treating the high protein concentration wastewater, such as the up-flow anaerobic sludge blanket (UASB), expanded granular sludge blanket (EGSB), anaerobic filter (AF), anaerobic continually stirred tank reactor (CSTR), anaerobic membrane bioreactor (AMBR), and anaerobic filter reactor (ABR) [3,14–18]. However, due to the elevated levels of organic matters (including the organic nitrogen) and the presence of some toxic substances, the anaerobic treatment of soybean protein wastewater was a bit difficult to satisfy the regulatory discharge limits [16]. The major barriers involved the unsatisfactory COD and NH_3-N removal efficiency, accumulation of volatile fatty acids (VFAs), poor sludge retention and insufficient stability [15].

Internal circulation (IC) anaerobic reactors can effectively solve the problem of the contradiction between poor sludge retention and short hydraulic retention time (HRT) that occurs in a traditional anaerobic reactor. Hence, they have become an distinguished representative in the third generation of anaerobic reactors [19,20]. In addition, the IC anaerobic reactor could offer a promising alternative for treating the soybean protein processing wastewater with high organic loading rate, powerful stress resistance, economic space utilization, excellent operation stability, and so on [21–24].

Nowadays, integrated biological treatment using an anaerobic–aerobic system always works more efficiently in denitrification and organics removal of wastewaters [25–27]. In particular, anoxic–oxic (A/O) or anaerobic-anoxic-oxic (A/A/O) process has been integrated with these anaerobic processes. For instance, a microbial fuel cell (MFC) that was embedded in a lab-scale AA/O reactor significantly improved both the nitrogen and phosphorus removal efficiency in wastewater [26]. Denitrification efficiency of UASB-A/O coupling system for the landfill leachate also rose as compared with that of UASB [28]. As a result, integration of anoxic-oxic (A/O) with IC anaerobic reactors would dramatically increase the capacity of denitrification and organics removal in soybean protein wastewater. However, still few references were reported relating to the treatment of the soybean protein wastewater in a pilot-scale IC anaerobic reactor integrated with A/O process (IC-A/O).

In order to provide technical guidance and theoretical reference for the soybean protein wastewater treatment in engineering application, pilot-scale IC-A/O coupling reactors were conducted in this study. The performance (COD and NH_3-N removal efficiency) of the coupling reactors was inspected during long-term operation and at the same time. The conditions in the coupling reactors (e.g. pH, temperature, volatile fatty acids (VFA)) were systematically monitored. The microbial community in the two reactors (IC reactor and A/O reactor) was also evaluated.

2. Materials and methods

2.1. Test water

Soybean protein wastewater was taken from air flotation process effluent (Gushen Biological Technology Co., Ltd; Shandong Provence), and the primary indicators of test water were shown in Table 1. The sludge was obtained from activated sludge by artificial domestication for several weeks. And the microorganism seeds were obtained from activated sludge of the domestic sewage treatment plant (Gushen Biological Technology Co., Ltd; Shandong Provence).

2.2. Experimental apparatus

2.2.1. Internal circulation (IC) reactor in pilot-scale

The unconventional design of pilot-scale IC reactor was experimented in Gushen Biological Technology Co., Ltd. The pilot-scale IC reactor was designed with the height of 7.3 m, base diameter of 2 m and effective volume of 20 m^3. The reactor was divided into five sections, including the mixing region, the first reaction zone (with the height of 2.75 m), the second reaction zone (with the height of 1.5 m), internal circulation system and exhalant region. Soybean protein wastewater was conveyed into the primary reaction region by rotational flow diffuser, which kept the superior mass transfer effect between influent and granular sludge. During the first reaction zone, large upflow liquid velocity (2.0 m L^{-1}) was generated due to the equipped internal circulation sludge backflow connection. Large upflow liquid velocity increased the exposure probability between wastewater and sludge. The water-sludge mixture was transferred in liquid-vapor separator, in which gas was emitted out of the system and the residue sludge was recycled into the first reaction zone, and then an internal circulation system was formed. After the disposition in the first reaction zone, one proportion of the effluent was entered into the internal circulation system, and another proportional feed into the second reaction zone to degrade the residue organic matter sequentially. Generated methane was collected and emitted into the air by the three-phase separator. The generation of methane during the pilot-scale study in IC reactor was negligible, so biogas collector was unnecessary.

2.2.2. Anoxic/oxic reactor in pilot-scale

An anoxic/oxic (A/O) reactor was developed and operated in Gushen Biological Technology Co., Ltd. A/O reactor was designed with the efficient volume of 45 m^3 and daily influent of 24 m^3. Anaerobic reaction zone, aerobiotic reaction zone and secondary clarifier were the primary components of the A/O reactor. Anoxic denitrification was fixed before aerobic nitrification. Raw water provided sufficient organic carbon for anoxic denitrification, and the basicity generated in anaerobic reaction zone made up for the need for aerobic nitrification.

The COD_{cr}, and NH_3-N of IC-A/O ultimate effluent were measured and the characterization of sludge during IC and A/O system were determined.

2.2.3. Physicochemical process for IC-A/O effluent in lab

After the disposition of pilot-scale IC-A/O coupling reactor, COD_{cr} in effluent could fully meet the basic discharge standard of second grade